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The Measurement of Productivity: A Primer with Examples for Small Businesses or Corporate Divisions

By

Thomas A. Barocci*, Mark Soeth,
and Kirsten R. Wever

WP #1371-82 November 1982

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*This report is one of a series under the aegis of the Productivity/Quality project within MIT's Sloan School of Management. The Project Director is Thomas A. Barocci, Associate Professor of Management. For further information contact Ms. Carolanne Foilb, Project Administrator, Sloan School of Management, MIT, 50 Memorial Drive, E52-454, Cambridge, MA 02139.

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The Measurement of Productivity:
with Examples for Small Businesses or Corporate Divisions

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Thomas A. Barocci*, Mark Soeth,
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What the average American small businessperson thinks about that ominous but pervasive concept -- productivity -- is that it's something they have in Japan, something we don't have enough of in the US, and something we can't do much about. So small American businesses very rarely measure their productivity. Unfortunately, these are often the very firms that have no choice but to make productivity their central concern if they want to stay economically viable. The main reason why they don't is that to small businesses the measurement and improvement of productivity appear both confusing and cost-ineffective. True, if each firm had to start from scratch, to collect its own data, to devise its own formulas and indices, and to reach isolated conclusions about how to use these, measuring and improving productivity would be inefficient. But things aren't as complex as most small businesses would have it.

Many authors believe there are few (if any) measures that can be applied to small businesses or corporate divisions which do not require adjustment for the individual characteristics of each firm. The measures presented in the following analysis are intended as tools to help management and staff monitor and analyze productivity. Whether one succeeds in adapting generic measures

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of this type (e.g., for use with incentive pay schemes) depends also on the involvement of the people who are going to be measured (and rewarded) in the process of setting the appropriate productivity/reward standards.[1]

This paper prepares a guide to the development of small business productivity measurement systems that can be adapted to a wide range of industries and company types. Contrary to popular opinion, it is possible and often highly cost-effective to compare inputs to outputs over time, and thus to identify trends and pinpoint areas in which productivity can be raised.

The factors that must be considered are illustrated in Figure 1. This paper is composed as follows: first, we discuss basic measures and indices; second, we consider how to measure inputs; the third section considers output measures and the data sources that help define outputs; fourth, we briefly illustrate these measurement principles with reference to a fictional small business; finally, we conclude with a short summary and some suggestions about how a small business or corporate division can most effectively tackle the problem of productivity.[2]

BASIC MEASURES

There are both total measures and partial measures of productivity. Partial measures consider the productivity of a specific input; e.g., labor.

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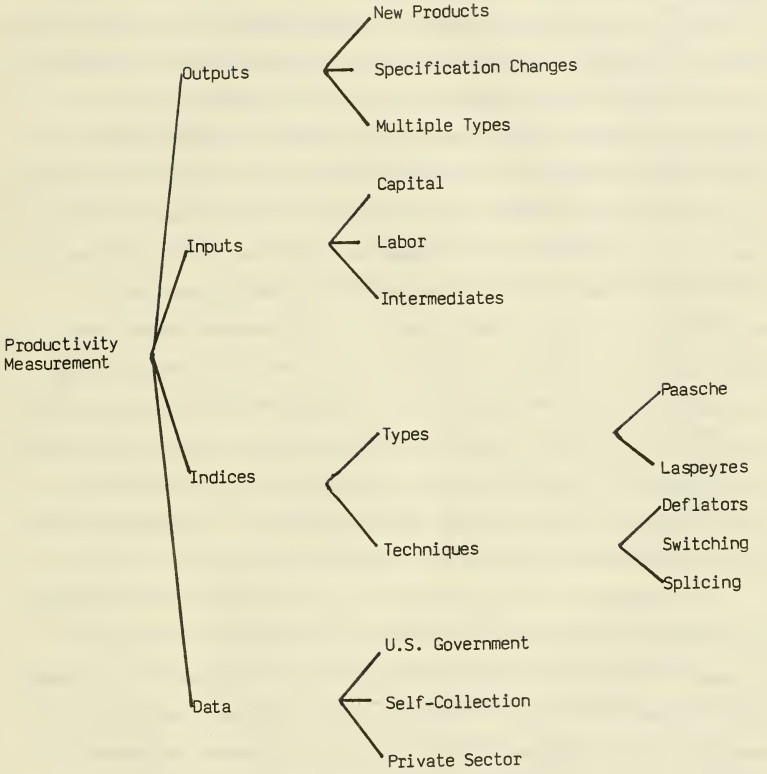
[1]Barocci, et. al., "Productivity, Industrial Relations and Human Resource Management: Football on a Soccer Field," M.I.T., Sloan School of Management Working Paper #1358-82, November 1982.

[2]For basic background information and more specific guides to the measurement of productivity, we refer the reader to the following: John Kendrick and David Creamer, Measuring Company Productivity, 1961; Leon Greenberg, A Practical Guide to Productivity Measurement, 1980; and The Handbook of Methods for Surveys and Studies, issued by the Bureau of Labor Statistics (BLS), and covering a variety of indices, data gathering methods, sampling methods and specifications.

Figure 1

Productivity Measurement Systems



Total measures take into account the effects of all inputs on aggregate output, including labor, capital, purchased goods and services (intermediates), and (more recently) energy.[1]

Since it's impossible to compare all inputs directly, they have to be translated into dollar terms and adjusted to remove the effects of inflation. Each input factor is then measured on the basis of weighted prices. Productivity is measured over a specific time period, so income figures (sales) should be adjusted to reflect the differences between the inventory at the beginning and end of that period. The period being measured is then compared to some previous period, usually called the base period. The point is to figure out rates of return, and see how efficiently inputs are contributing to production. Of course, it is also necessary to take into account capital depreciation. If depreciation in base year terms is greater than book value, the difference should be subtracted from gross income. This is done by dividing output (inventory adjusted) by labor (wages and salaries) plus intermediates (purchased services, materials, supplies) plus capital (capital investment income, interest and depreciation). The base year figure can then be compared with the rates of return for other years.

This measurement of total productivity is nothing more than a ratio of real outputs to real inputs in terms of the base period rate of return. So the numbers show how efficiently inputs are converted into outputs. Of course this measurement can't take into account all the intangible inputs (e.g., managerial style, government services, technological changes or improved resource allocations) that can crucially affect efficiency. So once

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[1]Given $Q = g(K,L,I,E)$, a total measure is $\frac{Q}{K+L+I+E}$

A labor partial would read Q/L.

productivity is measured, it's important to look beyond the numbers to the environment for clues about the intangible sources of productivity fluctations.

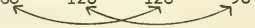
Partial measures are based on the same principles: divide base year output by labor input (salaries and wages), and compare over time. (It should be noted that this measure takes no account of variations in the efficiency of labor utilization.) Labor partials can also be obtained in a more direct manner by dividing weighted units by actual hours worked. (See Figure 2) It is important to keep in mind that the productivity increase shown in Figure 2 is probably not solely a result of work force improvements. Again, it is necessary to consider the effects of intangibles on productivity.

An index including output, employment, hours worked and output per hour also offers a labor partial that will reflect variations in the relationship between physical output and employee hours expended to create that output. A perceived change in labor productivity could reflect a series of factors; e.g., a recession, high interest rates, inflation, or, hypothetically, the fact that production workers were laid off while salaried employees were not, leading to an increase in administrative overhead and an inevitable decrease in 'labor productivity'. (See Appendix B for an explanation of how such indices are constructed.)

There are two general sorts of indices. If the base year is also the initial year of the index, the index is base-year-weighted (a Laspeyres index): divide price in a given period times quantity in the present period by present price times present quantity. If the current year is the base year, the index shifts each year to reflect changes in the rates of price movements and in productivity efficiencies (a Paasche index). In this case, divide price in a given period times quantity in that period by present price times

Figure 2 -- Partial Factor Productivity Example

	Units Produced		Allocated Man-Hours/Units	Weighted Units		Actual Hours	
	Base Year	Year T	Both Years	Base Year	Year T	Base Year	Year T
Producer A	4	12	5	20	60	60	41
Producer B	5	5	4	20	20	20	13
Producer C	10	20	2	20	40	40	26
				60	120	120	90



Labor Productivity in Year T is 1.33, a 33% increase over the base year.

quantity in that first given period.[1] (When inputs and outputs change frequently, Paasche indices are more useful in reflecting the dynamic environment.) To obtain a quantity-weighted (rather than price-weighted) Laspeyres index, divide a value index by a price-weighted Paasche index. (For an explanation of how to do this, refer to Appendix C.)

When indices are maintained over a long time period, the numbers often grow so large that they lose intuitive meaning. But the base year can be shifted to compensate for this problem. The concept can be extended by splicing to take into account technological innovations that make specifications obsolete. Splicing involves calculation of the ratio of new to old index numbers for overlapping years, and multiplication of the conversion factor by new index numbers, so that both indices are expressed in terms of the original one.

When prices move cyclically or seasonally, underlying trends can be identified by taking measurements at identical points in each cycle. If prices do not vary with the number of days per month, and thus are not subject to large or sudden shifts, a seasonal adjustment factor can be multiplied by measured prices to reflect underlying price movements. (See Appendix D for an illustration of this procedure.)

The cost of constructing these productivity indices can appear prohibitive. But price indices are available to the the public, and can be adapted relatively easily to an individual firm. In deciding whether to use a general index the businessperson must, of course, consider the costs

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[1] Laspeyres: $\frac{p_i q_i}{p_o q_o}$; Paasche: $\frac{p_i q_i}{p_o q_i}$, where 'p' is the price of goods and services represented by quantity 'q', in the present period 'o', or in some other period 'i'.

of labor, equipment, and information gathering, as well as the opportunity costs of constructing such an index from scratch.

THE MEASUREMENT OF INPUTS

Labor is traditionally measured in hourly terms, either in hours worked or in hours paid. The input of salaried employees can be estimated by calculating the ratio of indirect (salaried) to direct (hourly) workers, and multiplying by direct labor hourly input. Differences in the quality of various labor inputs should also be taken into account. Factors like age, education or experience can be measured directly; others, like motivation or intelligence, cannot.

Capital is defined as all non-human assets, both tangible and intangible, used in production. Tangible capital consists of fixed structures and equipment, inventories and land. Intangible (financial) capital includes working capital (cash and accounts receivable) and portfolio investments (funds not required by current production). The latter are not considered in productivity measurements because they do not contribute directly to production.

But valuing fixed assets is problematic: economic depreciation measures economic efficiency, while accounting depreciation is distorted in response to tax laws. Gross accounting values for depreciable capital stocks also implicitly assume that capital will function at 100% efficiency over its service life. This condition is, of course, rarely met, although depreciation schedules can compensate for this ideal assumption.

The perpetual inventory method is more accurate than any accounting method. It measures an asset beginning with its purchase price, and makes annual deductions for declines in economic efficiency. In any given year the sum of previously acquired asset values and current year purchases equals

current capital, which is deflated to refelect the base year. Another alternative is the book value method, which ceases to count undepreciated value as a capital component once economic efficiency reaches zero.

If service lives are indeterminate, rendering these methods hard to use, it can be helpful to adopt a fictitious leasing method. In this case, you treat fixed assets as being available through lease from other firms. The payment of the lease reflects the assets' value in use. The lessor's rate of return should also reflect business risks and the possibility of technological obsolescence.

The quality of intermediaries can usually be measured by market prices, which can be used directly as a component of total input. Supplier efficiencies can be traced by using a partial measure, including only intermediates in the denominator. While it might seem as though such a partial measurement is uninteresting, since intermediate prices cannot be controlled, the information they yield can indicate areas in which the purchase of intermediate goods and services could be eliminated or cut down to contribute to overall productivity.

Finally, indirect business taxes should also be included in productivity measurement, since they contribute directly to production by allowing for government-provided services.

OUTPUT MEASURES AND DATA SOURCES

Output measurements should consider output flows, rather than stocks. And the outputs under consideration should clearly relate to the operative inputs.

Where changing specifications or new products are involved, measuring output can be particularly difficult because of the dynamic component these

circumstances introduce. But by using a new index, the time at which the new product or specification was introduced can be considered the base year. It is then possible to compare new products with old ones by using the ratio of the man-hours per unit required to produce the new product to the time needed to produce some older product that was manufactured during the base year. This ratio can then be applied to the current year new product unit hours, yielding a corresponding base year new product figure.[1]

Hedonic regressions can be the most appropriate measurement technique when each product is unique. Here, you disaggregate a product into its various most crucial attributes (e.g., for a car: horsepower, mileage, size, etc.). Prices can change to reflect the particular combination of characteristics for a given product, with variations in quality across products.

How do you go about collecting all the data necessary to a productivity measurement system? Data-collection may often appear prohibitively time-consuming. But this problem can be off-set at least partially by using deflators constructed for some input (even if it's not actually used in production), and accepting some degree of error. Alternately, you can use publicly available price indices. Neither approach is perfect, but both can be helpful when it's impractical to create individually tailored indices.

It can also be helpful to use prepared indices as deflators. But not just any index will do. The choice must reflect the environment in which the

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[1]Note: This method assumes that productivity changes for the new product equal those for the comparison product, if the new product has been introduced during the base year. This may not always be the case.

data were gathered and the index's specifications.[1]

Information that is generally available can also be used to provide productivity benchmarks, to indicate major productivity problems. Direct comparisons between individual firms can be found in annual reports and the Securities and Exchange Commission's 10-K Forms. But using such data can be quite misleading unless you consider the substantial differences in the accounting processes they reflect.

A PRACTICAL EXAMPLE

This example is designed to illustrate some of the procedures explained in the body of our paper. The firm we considered will be referred to as SoCal Construction, Inc.; 1979 revenues approached $27 million. Productivity trends over time were of particular interest to this company. SoCal uses Laspeyres indices. Rebasing occurs every five years, since the technology is relatively stable and changes in input prices are evolutionary.

Output measurements are illustrated in Figure 3, labor inputs in Figure 4. The most important inputs in this industry are purchased goods and services -- intermediaries -- shown in Figure 5. Capital stocks are minimal, since this firm subcontracts so much of its work. Capital input calculations appear in Figure 6. Based on these factors, the firm calculated productivity in the manner shown in Figure 7. The determination of base period equivalents is of particular importance.

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[1]The Commerce Department price index biases productivity measures downward because it is a base-period-weighted cost index that will not reflect productivity in the quantity being measured; this biases the price index upward, resulting in an overvaluation of inputs. The problem also occurs with Laspeyres indices.

Interpreting productivity measurements is often more difficult than calculating them. It is crucial at the outset to understand the specific components of each number derived. Equally important is an understanding of the environmental factors affecting them. These considerations are particularly important in the evaluation of partial measures, which often fail to reflect efficiency changes in the quantities being measured.

Analysis of the measurements in Figure 7 indicate that total productivity has fallen, but that the problem is not a serious one. When revenues increased at 10% annually, efficiency increased by 3%. During the 1977-78 period of rapid growth, productivity dropped by 7% in one year, held constant, and rose again in 1979. These results are hardly surprising, since growth rates over 50% are invevitably accompanied by declines in efficiency. Similarly, what looks like a fall in labor productivity is simply a reflection of an unwise decision in 1976 to add workers in anticipation of a boom that never came. And capital productivity rose substantially with increasing growth rates, though the figures are artificially high, since lags in capital acquisition, in conjunction with the fact that there was no need for proportional increases, meant that the relative share of capital as an input decreased sharply.

An example of exogenously affected productivity changes is found in the intermediates category for 1979. Health regulations required a new kind of insulation; replacement material and additional labor costs decreased productivity. Environmental effects (e.g., changes among subcontractors and technological innovations), design alterations, changing accounting practices -- all these factors have an impact on productivity. So it's vital to consider each situation on its own unique merits, to understand the manifold influences of the environment, and to clarify the components of each measurement before jumping to conclusions about what it says about productivity.

FIGURE 3

Output Measurement Calculations

	1975	1976	1977	1978	1979
Sales-Homes	$6,435,000	$7,963,200	$12,826,128	$19,367,567	$27,201,813
+Finished Inventory	675,000	604,800	654,192	690,939	1,285,125
-Units sold not built current year	135,000	675,000	604,800	654,192	690,939
Current Value		7,983,000	12,875,520	19,404,314	27,795,999
Base Equivalent	6,975,000	6,945,840	10,557,926	14,364,155	21,541,190
Work in Process			198,240	923,194	1,070,937
			168,167	609,965	901,836
Sales Apartments		1,295,078	1,875,000	4,813,689	
Base Equivalent		1,156,320	1,537,500	3,342,840	
Total Base Period Equivalent	6,975,000	8,102,160	12,263,593	18,316,960	22,443,026

FIGURE 4

Input Calculations- Labor

Employee Type	1975		1976		1977		1978		1979	
	Hours Worked	Allocated Salary	Hours Worked	Allocated Salary	Hours Worked	Allocated Salary	Hours Worked	Allocated Salary	Hours Worked	Allocated Salary
Project Managers	3,760	$21,600	5,640	$38,102	9,200	$71,123	14,400	$152,000	18,400	$215,000
Base Equivalent				33,529		54,054		97,280		116,100
Administrative	1,850	8,000	1,880	8,690	3,680	19,987	3,600	23,984	3,710	31,215
				7,772		15,190		15,349		16,856
Interior Designer							1,040	8,750	1,800	15,200
								5,600		8,208
Owner	1,764	21,625	1,764	31,000	1,840	46,750	1,825	53,810	1,790	62,500
				27,280		35,530		34,438		33,750
Total Base Period Equivalents		51,225		68,581		104,774		152,667		174,914

FIGURE 5

Input Calculation- Intermediates

Subcontractors-	1975	1976	1977	1978	1979
Foundations	$ 71,518	$ 101,071	$ 180,159	$ 290,402	$ 362,368
Base Equivalent		90,241	141,857	203,505	227,205
Glazier/Framing/ Insulation		1,606,762	3,109,340	5,011,996	6,252,055
(Includes Floors and Roof)	1,136,382	1,430,039	2,428,339	3,297,366	4,156,320
Plumbing		338,274	684,553	1,102,442	1,375,895
	241,276	304,438	543,295	714,520	891,503
Electrical		180,309	364,886	588,167	733,925
	129,497	163,399	289,591	377,440	476,319
Roofing		189,880	368,005	593,193	740,198
	134,361	168,902	289,514	414,820	492,232
Floor Finishes		209,915	408,548	658,546	821,746
	148,538	187,424	316,703	454,169	562,731
Ceiling and Wall Finishes		253,131	492,753	794,277	991,113
	179,119	226,009	389,528	555,437	637,285
Interior Partition and Sheetrock		378,574	734,233	1,185,133	1,477,829
	267,883	338,012	573,400	828,764	986,378
HVAC		270,790	530,737	856,116	1,069,524
	191,614	242,016	424,389	633,900	658,826
Fixed Equipment		430,488	837,662	1,350,853	1,708,357
	304,618	384,363	649,125	944,352	1,157,490
Category					
Civil Works Base Equivalent		1,306,762	2,651,984	4,262,451	5,319,720
	977,023	1,232,794	2,413,827	2,959,972	3,455,760
Advertising		6,508	9,922	15,994	19,958
	4,689	5,916	7,751	11,107	13,572
Design		41,206	60,638	97,745	121,968
	29,688	37,459	47,374	67,878	82,938

FIGURE 5

Input Calculation- Intermediates (Continued)

Category-	1975	1976	1977	1978	1979
Accounting	$ 3,209	$ 4,686 4,170	$ 7,510 5,202	$ 10,128 6,978	$ 10,676 7,858
Land	336,027	477,820 425,260	953,204 750,554	1,442,038 1,010,537	1,760,366 1,140,619
Miscellaneous Direct Charge	11,372	15,785 14,349	30,319 23,687	48,872 33,938	60,984 41,469
Miscellaneous Overhead	3,168	4,398 3,998	7,276 5,684	11,729 8,144	14,636 9,952
Taxes	39,806	57,762 50,228	116,892 91,321	188,421 130,847	159,877 159,877
Total Base Period Equivalent Intermediates-	$4,209,788	$5,312,727	$9,381,141	12,653,682	$15,107,706

FIGURE 6

Input Calculations - Capital

Type	1975	1976	1977	1978	1979
Cash	$ 157,044	$ 200,871	$ 392,244	$ 641,142	$ 796,617
Deflated Equivalent	182,610	306,441		442,167	501,017
Accounts Receivable	209,250	272,232	485,637	851,737	1,110,928
	243,065	367,907		549,508	673,290
Inventory	675,000	604,800	654,192	690,939	1,285,125
	540,000	495,600		445,767	778,863
Work in Process	198,240			923,194	1,070,937
	156,094			650,136	649,052
Notes	675,000	665,280	906,240	2,636,700	3,269,358
	604,800	708,000		1,818,414	2,056,200
Implicit Leases; Structures and Land (Base Period Equivalents)	3,000	3,000	3,000	4,700	4,700
Equipment Leases	12,680	8,000	21,960	28,200	24,020
Total- Base Period Equivalents	1,731,974	1,581,475	2,059,148	3,938,892	4,687,142
Investor's Capital Input	2,719,199	2,482,887	3,232,862	6,184,060	7,829,813

Calculation of Base Period Rate of Return = Net Income/Capital

$$= \frac{\$2,713,987}{\$1,731,974}$$

$$= 1.57$$

Sample Calculation Investor's Capital Input =

Capital period t X Base Period Rate of Return

For 1977 = $1,581,457 x 1.57 = $2,482,887

NOTE: Equipment Leases include office equipment, furnishings, and vehicles.

FIGURE 7

Productivity Calculations

Category	1975	1976	1977	1978	1979
Total Productivity	1.00	1.03	.96	.96	.97
Index Value	100	103	96	96	97
Value Added Productivity	1.97	1.09	.86	.88	.92
	100	55	44	45	47
Capital	2.57	3.26	3.79	2.96	2.87
	100	127	147	115	112
Labor	136.2	118.1	117.1	120.0	128.3
	100	92	79	87	90
Intermediates	1.66	1.53	1.31	1.45	1.49
	100	92	79	87	90
Selected Intermediates					
Civil Works	7.14	6.57	5.10	6.19	6.49
	100	92	71	87	91
Glaze/Frame/Insulate	6.13	5.64	5.05	5.56	5.40
	100	92	82	91	88
Plumbing	28.91	26.61	22.57	16.60	25.15
	100	92	78	57	87
HVAC	36.40	33.48	28.83	28.85	20.98
	100	92	78	79	58
Miscellaneous					
Direct Charge	613.4	564.7	517.7	539.7	541.2
	100	92	84	88	86

CONCLUSIONS

This paper has illustrated that there isn't anything mysterious about the measurement of productivity at the level of the firm. A manager applying the following steps can construct an effective measurement system:

1) Determine the objectives, the quantities to be measured, and the reasons for measuring them;

2) Thoroughly consider the costs and benefits of adapting vs. creating appropriate indices;

3) Don't lose sight of intangibles that affect or are affected by productivity and the measurement process

   - in the creation of measurements
   - in the measurement process
   - in the interpretation of index numbers;

4) Were there are incentive schemes or other programs to raise productvity, allow management style to include and involve the people affected

   - in the program's formulation
   - in its maintenance
   - in its evaluation.

Used in conjunction with more traditional financial reporting systems, productivity measurements can provide the small business with the knowledge required to reverse the disquieting trend of decreasing productivity. The measurement of productivity should be undertaken only after a thorough cost-benefit analysis has been conducted. This analysis should clarify trade-offs between different measures, between different types of data, and

between the adaptation versus creation of productivity indices. The decisions that follow will have to reflect the manager's individual experience and discreet judgment. This element of subjectivity carries through to the final stages of measurement and, of course, pervades the interpretation of results. A clear understanding of how a particular measurement system works is the most basic ingredient for its flexibility and usefulness.

APPENDIX A

A Labor Partial

Year	Output (Millions)	Employment (Thousands)	Hours Worked All Persons (Millions)	Output Per Hour (Millions)
1966	$26,441	1,147	2,332	98.8
1967	26,385	1,095	2,222	100.0
1968	31,464	1,194	2,396	105.4
1979	34,204	1,264	2,569	98.4
1970	33,058	1,221	2,437	97.0
1971	44,418	1,477	2,943	102.5
1972	55,206	1,692	3,337	106.0
1973	58,613	1,678	3,317	101.6
1974	48,086	1,406	2,767	90.4
1975	44,070	1,197	2,338	90.5
1976	57,844	1,220	2,407	104.8

Output is in constant 1967 terms.

APPENDIX B

Index Construction - Base Case

A. Given Indices	Base Year	Year T	Year T+1
1) Output (Q)	100	105	110
2) Labor (L)	100	130	160
3) Capital (C)	100	135	138
4) Intermediates (I)	100	130	145

B. Deflation to base year dollar values

Value	Base Year Value	Year T Deflated Value	Year T
Q	$5,000,000	$7,320,000	$ 6,971,428
L	800,000	960,000	738,461
K	480,000	520,000	355,555
I	3,720,000	4,120,000	3,169,230

C. Index Construction

TFP = [Q/(K+L+I)] (Index #) (100)

Base Year	1.00	100
Year T	1.74	174
Year T+1	1.63	163

Note: Deflated Year T Value = $\frac{\text{Year T Value}}{\text{(Index Number) (.01)}}$

APPENDIX C

Quantity-Weighted Index

$$\frac{p_i q_i}{p_o q_o}$$

Therefore:

Value Index		Output Index= (Laspeyres)		Output Index (Paasche)
	divided by		is equal to	
$\frac{p_i q_o}{p_o q_o}$		$\frac{p_i q_o}{p_o q_o}$		$\frac{p_i q_i}{p_i q_o}$

APPENDIX D

Cyclical or Seasonal Adjustment

1. A four quarter centered moving average is calculated for the formula:

$$\bar{M}_t = 1/8\ (X_{t-2} + 2X_{t-1} + 2x_t + 2X_{t+1} + X_{t+2})$$

2. Specific sesonals are then obtained:

$$SI = X_t/\bar{M}_t$$

3. Average seasonals result from:

$$\bar{S}_q = \sum_{1}^{N} SI/N, \quad \text{where N is \# of years.}$$

4. Primarily because of rounding error, these numbers do not add to four (the number of seasons), so a further adjustment is made:

$$\text{Let } z = 4/\sum_{1}^{4} \bar{S}/_q, \quad \text{then } \hat{S}q = z\bar{S}q$$

5. Seasonally adjusted figures are then developed:

$$\hat{x}_i = x_i/\hat{s}_q$$

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